ORIGINAL ARTICLE

Maximal lipidic power in high competitive level triathletes and cyclists

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Objective: To describe the fat-oxidation rate in triathlon and different modalities of endurance cycling.
Methods: 34 endurance athletes (15 male triathletes, 4 female triathletes, 11 road cyclists and 4 male mountain bikers) underwent a progressive cycloergometer test until exhaustion. Relative work intensity (VO_{2max}), minimal lactate concentration (La^{-}_{min}), lactic threshold, individual lactic threshold (ILT), maximal fat-oxidation rate (Fat_{max}, Fat_{max} zone) and minimal fat-oxidation rate (Fat_{min}) were determined in each of the groups and were compared by means of one-way analysis of variance.
Results: No significant differences were found for Fat_{max}, Fat_{min} or for the Fat_{max} zone expressed as fat oxidation rate (g/min). Intensities −20%, −10% and −5% Fat_{max} were significantly lower for mountain bikers with respect to road cyclists and female triathletes, expressed as % VO_{2max}. Intensities 20%, 10% and 5% Fat_{max} were significantly lower for mountain bikers with respect to male triathletes and female triathletes, and for male triathletes in comparison with female triathletes, expressed as % VO_{2max}. Lactic threshold and La^{-}_{min} did not show significant differences with respect to Fat_{max}. Lactic threshold was found at the same VO_{2max} with respect to the higher part of the Fat_{max} zone, and La^{-}_{min} at the same VO_{2max} with respect to the lower part of the Fat_{max} zone.
Conclusions: The VO_{2max} of Fat_{max} and the Fat_{max} zone may explain the different endurance adaptations of the athletes according to their sporting discipline. Lactic threshold and La^{-}_{min} were found at different relative work intensities with respect to those of Fat_{max} even though they belonged to the Fat_{max} zone.

Fat and carbohydrates (CHO) are the main energetic substrates of aerobic metabolism that resynthesise the ATP in the skeletal muscle. The relative use of fat and CHO during exercise may vary in an important way and depends fundamentally on the maximal oxygen uptake VO_{2max}.[1] Moreover, it should be taken into account that, during exercise, women oxidise more intramuscular triglycerides than men,[2] and use less muscle glycogen.[3]

In endurance specialities, having a large capacity to metabolise CHO is a determining factor for performance, but so is the ability to economise this substrate as an effect of a greater capacity to use fat.[4] It has been observed that athletes have a lower fat-oxidation rate at low and high intensities compared with moderate intensities.[1 5] Also, there is a relative individual intensity at which the maximal fat-oxidation rate is produced.

Until recently, the methods followed by some authors only measured the athletes fat-oxidation rate in a reduced number of work intensities: two,[5–7] three[1 8 9] or four.[10] Now there is a method to measure the fat-oxidation rate for each of the relative work intensities, by means of indirect calorimetry and using stoichiometric equations.[11] However, this method has only been applied in a few studies carried out with cyclists.[11–13]

Some authors have observed that cycling endurance performance at a concrete work intensity improves with a training focused on this intensity.[14] After this principle (training specificity), other authors have observed that the fat-oxidation rate increases specifically for the concrete intensity that has been trained.[7] Thus, differences in the training of triathlon and cycling endurance modalities may produce different adaptations of the fat-oxidation rate at each of the aerobic work intensities.

The aim of this study was to use a cross-sectional design to describe the fat-oxidation rate in different modalities of endurance cycling and triathlon (mountain biking and road cycling in men, and short distance men's and women's triathlon), where the pace of the race is developed at different relative work intensities.

METHODS

Participants

A total of 34 athletes, mean (standard deviation (SD)) age 23.8 (4.7) years, and different sporting specialities participated in the study: short-distance male triathletes (n = 11) and female triathletes (n = 4), road cyclists (n = 11) and male mountain bikers (n = 4). These participants were all the endurance athletes included in our study group with a high performance level. They were all active competitors at national and international performance levels. The mean level of competitive experience was 4.5 (1.7) years. The study was carried out during the competitive periods in the individual schedule of the 2004 season. The athletes were informed of the procedures they would have to undergo. All experimental procedures were approved by the ethics committee of the High Performance Centre of Sant Cugat.

Study protocol

The tests were conducted for 4 weeks and always during the afternoon. Before the trial, during the 2 days before the test, all the athletes had to eat a high-CHO diet (70–80%) and perform endurance training at low intensities (40–50% VO_{2max}). The laboratory test was conducted on a cycloergometer with electromagnetic brakes (Cardgirus; G&G Innovación, La

Abbreviations: BMI, body mass index; CHO, carbohydrate; Fat_{max}, maximal fat-oxidation rate; Fat_{min}, minimal fat-oxidation rate; ILT, individual lactic threshold; La^{-}_{min}, minimal lactate concentration; VO_{2max}, maximal oxygen uptake

Table 1 Comparison of the anthropometric variables of the groups studied (mean (SD))

	Age (years)	Height (cm)	Body mass (kg)	BMI (kg/m^2)
TM	26.4 (4.3)	174.6 (6.8)	73.0 (7.9)*	23.6 (1.9)
TF	20.5 (1.7)	165.7 (6.5)	60.1 (4.9)	21.9 (0.1)†
C	21.1 (4.5)	176.7 (6.8)	67.1 (5.6)	21.5 (1.3)†
M	23.0 (4.7)	178.1 (5.2)	71.3 (7.3)	22.5 (1.9)
Total	23.8 (4.7)	176.3 (6.6)	69.4 (7.6)	22.6 (1.8)

BMI, body mass index; C, road cyclists; M, mountain bikers; TF, female triathletes; TM, male triathletes.
*$p<0.05$ (significant differences with respect to group TF).
†$p<0.05$ (significant difference with respect to group TM).

Bastida, Alava, Spain). After a 10-min warm-up at 100 W, the test started with an initial stage of 130 W for the women and 200 W for the men. The workload was increased by 30 W every 4 min, until the athlete reached exhaustion. Athletes were familiarised with this kind of protocol.

Gas exchange variables

The ventilatory frequency, tidal volume, fraction of O_2 exhaled, fraction of CO_2 exhaled, ventilatory volume, rate of ventilatory exchange and oxygen consumption were measured in real time, breath by breath, throughout the test, by means of an integrated system of indirect calorimetry (Quark PFT; Cosmed, Rome, Italy). VO_{2max} was determined as the mean value of the VO_2 of the last 30 s of effort, when at least two of the criteria recommended by the British Association of Sport and Exercise Sciences[15] were fulfilled.

Capillary blood lactate

During the last 15 s of each stage, as well as at the third minute after the end of the effort, the lactic acid concentration (La^-_{max}) was measured. This final recording was considered to be La^-_{max}.[16] Lactate concentration was determined in a portable lactate analyser (Lactate Pro Arkray, Kyoto, Japan). For this analysis, blood samples were taken from the ear lobe. Once the cycloergometer test was finished, the evaluation of La^-_{max} with respect to the power developed was adjusted by a second-order polynomial equation, which allowed the determination of the La^-_{min} and the individual lactic threshold (ILT) of each participant of the study. The La^-_{min} was determined as the minimum La^- measured during the test. The ILT was calculated as the La^-_{min} plus the concentration of a fixed lactate value established at 1.5 mM.[17] In addition, the lactic threshold was determined as the work intensity at which the La^- started to increase progressively.[18] The values of La^-_{min}, lactic threshold and ILT were expressed as La^- (mM), VO_2 (mL/kg/min), % VO_{2max} and heart rate (beats/min).

Determination of the fat-oxidation rate

The fat-oxidation rate was calculated by means of the equation proposed by Frayn,[19]

$$\text{Fat oxidation} = (1.67 \times VO_2) - (1.67 \times VCO_2)$$

in which it is assumed that the excretion of nitrogen in urine is negligible, using as values for VO_2 and VCO_2 the average of the measures (litres/min) realised during the last 2 min of each of the stages.

For the determination of the fat-oxidation rate, the point of maximal fat oxidation rate (Fat_{max}), expressed as an absolute value (g/min), was calculated for each of the participants of the study. With these data, a curve of the fat-oxidation rate versus the relative work intensity (% VO_{2max}) was constructed. The function was used to calculate the following relative variables: Fat_{max} (% VO_{2max} at which the greatest fat-oxidation rate was found), Fat_{min} (% VO_{2max} at which the lowest fat oxidation rate was reached (R = 1.0)) and the % VO_{2max} corresponding to 5%, 10% and 20% Fat_{max}. The Fat_{max} zone was defined as the range of relative work intensities between +10% and –10% Fat_{max}.[11]

Statistical analysis

Descriptive statistics were generated for all variables. To compare the physiological variables between the different groups of study, a one-way analysis of variance test was carried out. The determination of the Pearson correlation coefficient was used to verify the existence of relationships between the different variables studied, taking the relationships into account when $r \geqslant 0.8$. The significance level was determined at $p<0.05$ for all statistical tests carried out.

RESULTS

No significant differences were found for the different anthropometric variables studied between the different groups, except for the body mass, which was significantly greater in the male triathlete group than in the female triathlete group, and for the body mass index (BMI (weight (kg)/height^2(m^2)), which was higher in the male triathlete group than in the female triathlete and road cyclists groups (table 1).

With respect to the maximal cardiorespiratory and metabolic variables, the female triathlete group had a lower $VO_{2max,}$ expressed in absolute values, than the other study groups, and the male and female triathlete groups a lower maximum heart rate than the mountain biker group. No significant differences were observed regarding the maximal La^-_{max} (table 2).

No significant differences were found between the different groups of the study for the lactic threshold, expressed as La^-, or as relative (ml/kg/min) or absolute (l/min) VO_2, or as heart rate. La^-_{min} only showed significant differences between male triathletes and road cyclists when expressed as La^- (1.9 (0.7) *v* 1.0 (0.2) mM, respectively).

The ILT was found at a significantly higher La^- in the male triathlete group than in the other groups. When the ILT was expressed in absolute VO_2, it was significantly lower for the female triathlete group than in the other groups, although the ILT presented no significant differences when it was expressed in relative VO_2 values. Finally, when the ILT was expressed as HR, it was significantly higher for the mountain biker group than in the female triathlete group (table 3).

La^-_{min}, lactic threshold and ILT, expressed in terms of % VO_{2max}, did not show significant differences between the different groups of this study.

The average Fat_{max} was 0.45 (0.12) g/min, and was found at a relative work intensity of 52.3 (7.0)% VO_{2max}, whereas the Fat_{min} value was found at a relative work intensity of 87.8 (6.8)% VO_{2max}. The Fat_{max} zone was found to be between 43.3 (6.6) and 62.3 (7.0)% VO_{2max}, which corresponded to a range between −8.7 (4) and 10.5 (8.4)% of the mean Fat_{max} value. At intensities above the upper limit of the Fat_{max} zone (+ 10% Fat_{max}), the fat-oxidation rate deceased markedly.

Table 2 Comparison of the maximum cardiorespiratory and metabolic variables of the groups studied (mean (SD))

	VO_{2max} (ml/kg/min)	VO_{2max} (l/min)	HR_{max} (beats/min)	$La^-{}_{max}$ (mM)
TM	58.8 (4.4)	4.2 (0.5)*	180.4 (11.5)†	8.3 (2.7)
TF	58.4 (6.9)	3.5 (0.2)	177.0 (2.3)†	7.4 (3.3)
C	64.8 (5.5)	4.3 (0.3)*	190.2 (6.5)	8.1 (1.8)
M	65.6 (5.9)	4.6 (0.2)*	197.8 (9.5)	10.4 (3.7)
Total	61.5 (5.9)	4.2 (0.5)	185.2 (11.1)	8.4 (2.6)

C, road cyclists; HR_{max}, maximal heart rate; $La^-{}_{max}$, maximal lactate concentration; M, mountain bikers; TF, female triathletes; TM, male triathletes; VO_{2max}, maximal oxygen uptake.
*$p<0.001$ (significant differences with respect to group TF).
†$p<0.05$ (significant differences with respect to group M).

Neither significant differences for the Fat_{max} were found between the different groups of study, nor for the different relative intensities evaluated (5%, 10% and 20% Fat_{max}), and for the Fat_{min}, expressed all these terms as fat-oxidation rate (g/min). No difference was found for the limits of the Fat_{max} zone, expressed as percentages of the difference with respect to the Fat_{max}. However, when the fat-oxidation rate was expressed as % VO_{2max}, significant differences were found for the different relative intensities evaluated, except for the Fat_{min}.

Relative work intensities −20%, −10% and −5% Fat_{max} were significantly lower for the mountain biker group than for the road cyclist and female triathlete groups when they were expressed as % VO_{2max}. Relative work intensities 20%, 10% and 5% Fat_{max} were significantly lower for the mountain biker group than for the male and female triathlete groups, and for male triathletes in comparison with female triathletes when they were expressed as VO_{2max} (fig 1, table 4).

At the same time, the Fat_{max} did not correlate with the BMI and showed a very low correlation with the VO_{2max}.

$La^-{}_{min}$ was found at a significantly lower relative work intensity than Fat_{max} (42.0 (16.9) *v* 52.1 (6.8)% VO_{2max}, respectively). Lactic threshold was found at a significantly higher relative work intensity than Fat_{max} (64.6 (8.9) *v* 52.1 (6.8)% VO_{2max}, respectively). No significant differences were found for the $La^-{}_{min}$ with respect to relative intensities of the lower part of the Fat_{max} zone (between −20% and −5% Fat_{max}; 42 (16.9) *v* 33.1 (6.4) –48.1 (6.8)% VO_{2max}, respectively), or for the lactic threshold with respect to relative intensities of the higher part of the Fat_{max} zone (10% Fat_{max} to be precise; fig 2).

DISCUSSION

The Fat_{max} of the sample studied presented a relative intensity of 52% VO_{2max}, and the range of values varied between the 43% VO_{2max} of the mountain biker group, the 52% and 53% VO_{2max} of road cyclist and male triathlete, groups respectively, and the 59% VO_{2max} of the female triathlete group. This range of Fat_{max} agreed with the data on cycloergometer efforts found in the literature (33–75% VO_{2max}).[1 5–13]

When relating the data of this study to those of other authors, reference should be made to two important aspects. Firstly, few studies have measured the Fat_{max} of trained cyclists. To this effect, a Fat_{max} at a relative intensity of 65% VO_{2max} has been observed in female cyclists[9] and of 57% and 75% VO_{2max} in highly trained cyclists of both sexes.[8] The remaining studies have been conducted on less well trained populations such as sedentary men (36–55% VO_{2max}),[5 10] sedentary women (65% VO_{2max}),[7] students of physical education of both sexes (49% VO_{2max}),[6] and male amateur cyclists (33–65% VO_{2max}).[1 13] The second aspect to be remarked on is of a methodological nature: as the evaluation of the fat-oxidation rate at all the submaximal work intensities has been rarely applied, few studies have been found that can be used as reference.[11–13]

To this effect, authors who have measured the Fat_{max} in amateur cyclists found Fat_{max} at 63–64% VO_{2max} and at 0.6 g/min, and a Fat_{max} zone at 51–55% and 69–72% VO_{2max}. Fat oxidation was null above 81–89% VO_{2max}. These results are higher than those obtained with respect to the road cyclist group of this study (Fat_{max}, 52% VO_{2max}; Fat_{max} zone, 43–62% VO_{2max}), which may be because the performance level of the road cyclist group was heterogeneous. The Fat_{min} found in this study (88 (7)% VO_{2max}) was similar to that observed in amateur cyclists (89 (3)% VO_{2max}).[11]

The fact that no significant differences were found in the Fat_{max} zone, expressed in absolute values, between the different groups in this study may be due to the heterogeneity of the road cyclist and male triathlete groups. It has been observed in other studies that, in cyclists with a greater level of VO_{2max}, the Fat_{max} expressed in absolute values is greater than that seen in cyclists

Table 3 Comparison of the cardiorespiratory and metabolic variables corresponding to the ILT of the groups studied (mean (SD))

	La^- (mM)	VO_2 (ml/kg/min)	VO_2 (l/min)	VO_{2max} (%)	HR (beats/min)
TM	3.44 (0.73)	45.7 (4.3)	3.2 (0.4)†	74.3 (8.6)	154 (14)
TF	2.77 (0.79)*	43.2 (3.9)	2.6 (0.0)	70 (0.8)	143 (8)
C	2.53 (0.17)*	51.3 (5.4)	3.5 (0.3)†	77.4 (4.4)	162 (8)
M	3.07 (0.80)*	51.0 (5.1)	3.6 (0.1)‡	77.8 (1.7)	169 (7)§
Total	3.01 (0.71)	47.9 (5.5)	3.3 (0.4)	75.2 (6.6)	157 (13)

C, road cyclists; HR, heart rate; La^-, lactate concentration; M, mountain bikers; TF, female triathletes; TM, male triathletes; VO_2, oxygen uptake; VO_{2max}, maximal oxygen uptake.
*$p<0.01$ (significant differences with respect to group TM).
†$p<0.001$ (significant differences with respect to group TF).
‡$p<0.01$ (significant differences with respect to group TF).
§$p<0.05$ (significant differences with respect to group TF).

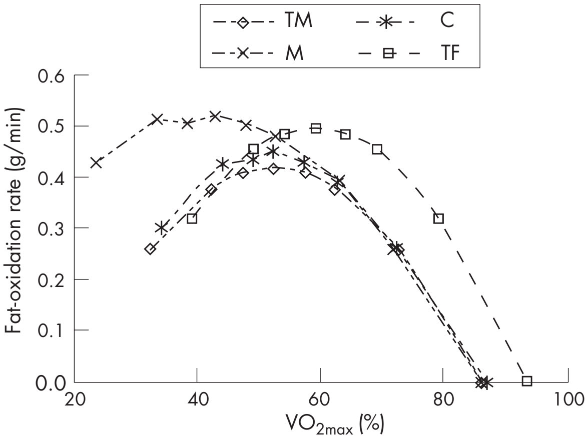

Figure 1 Comparison of the relationship of fat-oxidation rate (g/min) and the relative work intensity (% VO_{2max}) of the different groups studied. C, road cyclists; M, mountain bikers; TF, female triathletes; TM, male triathletes.

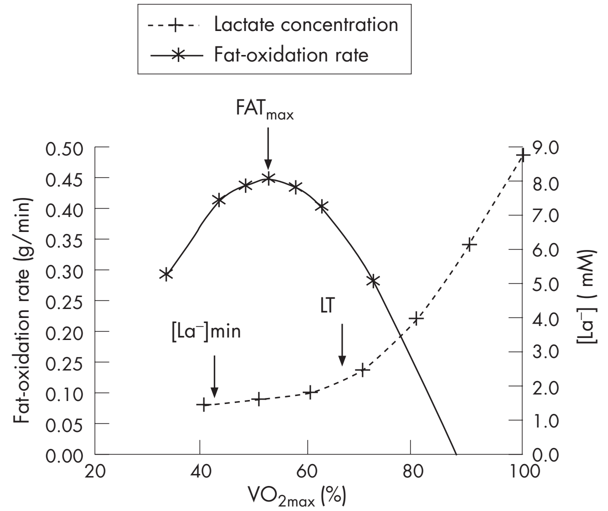

Figure 2 Comparison of La^{-}_{min} and lactic threshold (LT) and Fat_{max} zones in terms of relative work intensity, of the total group studied (*no significant differences for La^{-}_{min} with respect to −20% and −5% Fat_{max}; †no significant differences for lactic threshold with respect to 10% Fat_{max}).

with a lower VO_{2max}.[12] At the same time, the Fat_{max} did not correlate with either the BMI or the VO_{2max}. The same results are reported by Achten and Jeukendrup[12] for the BMI, although, in contrast with their findings, a significant, but low, correlation was found in this study for the VO_{2max} ($r = 0.636$; $p<0.01$).

With respect to the Fat_{max} zone, significant differences were found when expressed in relative work intensity. In this sense, in the female triathlete group, the relative work intensities at which the Fat_{max} zone was found were greater than in the other male groups and, in many participants, significantly so. This fact might be attributable not so much to the type of training as to the differentiation due to the effects of the female hormones, the oestrogens. These hormones mean that, at a relative work intensity, the intramuscular triglycerides are used in a more important way in energy output,[2] which is facilitated by greater reserves of intramuscular triglycerides in women.[20]

On the other hand, regarding the male groups, significant differences were found between mountain biker and male triathlete groups with respect to the high part of the Fat_{max} zone, and between mountain biker and road cyclist groups with respect to the low part. These differences may be attributable to the type of training of the different sporting modalities. It is well known that aerobic endurance training enhances fat-oxidation capacity because of the increase in the mitochondrial enzyme content and in the enzymes responsible for β-oxidation.[3 21] The fact that the Fat_{max} zone of the mountain biker group was found at a significantly lower % VO_{2max} than in the road cyclist and male triathlete groups might be attributable to the type of training carried out according to the competition requirements of each of the sporting modalities. It has been observed that the percentage of total competitive time developed below the first ventilatory threshold in high-level road cyclists corresponds to 71.5–74.6%, compared with 18.5% in high-level mountain bikers. Regarding the zone between the first and second ventilatory thresholds, the percentage of total competitive time developed in this zone is 22.7–25.2% in road cycling and 51.4% in mountain biking, and regarding the zone above the second ventilatory threshold, it is 2.7–3.3% in road cycling stages competitions,[22 23] compared with 30.1% in high level 1-day mountain-bike competitions.[24] Therefore, it is logical that the lower part of the Fat_{max} zone of the road cyclist group is significantly higher than that of the mountain biker group. Moreover, the pace of the race of the male triathlete group is found around the ILT,[25] which is why it seems logical to consider that the higher part of the Fat_{max} zone is significantly higher than that of the mountain biker group.

It seems obvious that when the same relative work intensity is measured, after an endurance training period, the fat oxidation will increase,[21] as this type of training has been

Table 4 Comparison of the relative intensities (% VO_{2max}) at which the variables of the fat-oxidation rate are found in the groups of study (mean±SD)

	TM	TF	C	M	Total
−20% Fat_{max}	32.6±5.3	39.3±0.8*	34.2±6.5*	23.6±5.2	33.1±6.4
−10% Fat_{max}	42.6±5.3	49.3±0.8*	44.2±6.5*	33.6±5.2	43.1±6.4
−5% Fat_{max}	47.3±5.3	54.3±0.8*	49.2±6.5*	38.6±5.2	48.1±6.4
Fat_{max}	52.6±5.3	59.3±0.8‡	52.3±7.2	43.0±4.4†	52.1±6.8
+5% Fat_{max}	57.6±5.3	64.3±0.8‡	57.3±7.2	48.0±4.4†	57.1±6.8
+10% Fat_{max}	62.6±5.3	69.3±0.8‡	62.3±7.2	53.0±4.4†	62.1±6.8
+20% Fat_{max}	72.6±5.3	79.3±0.8‡	72.3±7.2	63.0±4.4†	72.1±6.8
Fat_{min}	86.4±5.4	93.8±3.0	87.3±8.6	86.4±7.8	87.6±6.9

C, road cyclists; Fat_{min}, minimal fat-oxidation rate; Fat_{max}, maximal fat-oxidation rate; M, mountain bikers; TF, female triathletes; TM, male triathletes.
*$p<0.05$ (significant differences with respect to group M).
†$p<0.05$ (significant differences with respect to groups TM and TF).
‡$p<0.01$ (significant differences with respect to group TM).

What is already known on this topic

- Until recently, methods followed by some authors measured only the athletes' fat-oxidation rate at a reduced number of work intensities.
- Now, a method exists to measure the fat-oxidation rate for all the range of aerobic work intensities, by means of indirect calorimetry and using stoichiometric equations.
- This method, however, has only been applied in a few studies carried out with amateur cyclists.

What this study adds

- This study used the indirect calorimetry method to calculate the fat-oxidation rate on high performance-level cyclists and triathletes.
- The results show different adaptations of the endurance athletes' fat-oxidation rate depending on their sporting discipline.

observed to enhance not only the oxidation of intramuscular triglycerides in an absolute manner but also the relative work intensity at which fats are oxidised.[7] Consequently, performance also improves.[3]

In any case, we should be cautious when interpreting the data of this study. It has to be remarked that the group sample sizes vary considerably and are not adequately powered. This is due to the difficulty in finding elite athletes of the different modalities.

Regular physical activity at low and moderate intensities enhances the mobilisation of intramuscular triglycerides[7] and subcutaneous fat oxidation.[1] This variable may also be used to orient training in medium-endurance and long-endurance specialities, as this type of training increases the muscular capability to oxidise fats and, in this way, to economise the use of glycogen, thus improving performance.[4]

Another important finding of this study is the relationship of Fat_{max} and Fat_{max} zone with respect to $La^{-}{}_{min}$ and lactic threshold. $La^{-}{}_{min}$ was found at a lower relative work intensity than Fat_{max}, although it coincided with that of the lower part of the Fat_{max} zone. This suggests that $La^{-}{}_{min}$ may be more related to lactate clearance capability[26] of blood than to fat-oxidation rate. Lactic threshold was found at a higher relative intensity than Fat_{max}, coinciding with the higher part of the Fat_{max} zone. So, lactic threshold appears when the fat-oxidation rate starts to decrease. One of the main causes of this may be an increase in the glycolytic flux, as it has been suggested to induce intramuscular changes that affect fat oxidation. A decreased muscle pH as a result of increased proton release during anaerobic glycolysis has been proposed by Starritt *et al*[27] as a possible mechanism explaining decreased fat oxidation.

Traditionally, lactic threshold has been considered as one of the performance determinant factors in road cycling,[28] and has been used to control endurance sports training.[29] The findings of this study highlight the importance of the Fat_{max} and the Fat_{max} zone as variables to be taken into account when determining training rhythms.

In conclusion, the relative work intensity at which the Fat_{max} and the Fat_{max} zone are found may explain the different endurance adaptations of the athletes according to their sporting discipline. Furthermore, lactic threshold and $La^{-}{}_{min}$ were found at different relative work intensities with respect to Fat_{max}, but they belong to the Fat_{max} zone. Longitudinal studies are required to evaluate the effect of endurance training on athlete fat oxidation.

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COMMENTARY

Evidence indicates that the training-induced increase in fat oxidation is primarily due to increased oxidation of non-plasma-derived fatty acids. Fat oxidation in high-intensity exercise is lower than in moderate-intensity exercise because of decreased fatty acid delivery to exercising muscles. High carbohydrate diet during high-intensity exercise increases fat oxidation. This is a good-quality, newly approached and original study conducted on triathlon athletes and cyclists of high competitive level. The authors have meticulously designed a cross-sectional study to measure the rate of fat oxidation of endurance athletes. The claims in the study are technically well supported. A new concept of measuring the rate of fat oxidation at relative work intensities by indirect calorimetry and using stoichiometric equations has been devised, which has been used previously in only a few studies. Significant results have been drawn from the study. This study needs to be designed further as a longitudinal one with a large population, including various other aspects such as longer duration of the study, training schedule, dietary pattern of the athletes and hormonal effects. If the results obtained are significant, it should be a useful tool for researchers world wide in the field of sports medicine.

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Dr Arroyo graduated from the University Autonoma of Guadalajara and completed a fellowship in sports medicine in Columbus, Ohio. He focuses on the pathologies of soccer players, related to physiology and traumatic injuries. He lectures and publishes research on soccer internationally. He has worked in sports medicine since 1989 with professional and amateur athletes from a variety of sports, including five professional soccer teams, American football, professional basketball, Olympic volleyball and tae kwon do teams, and is also medical advisor to the marathon organisation in Guadalajara.

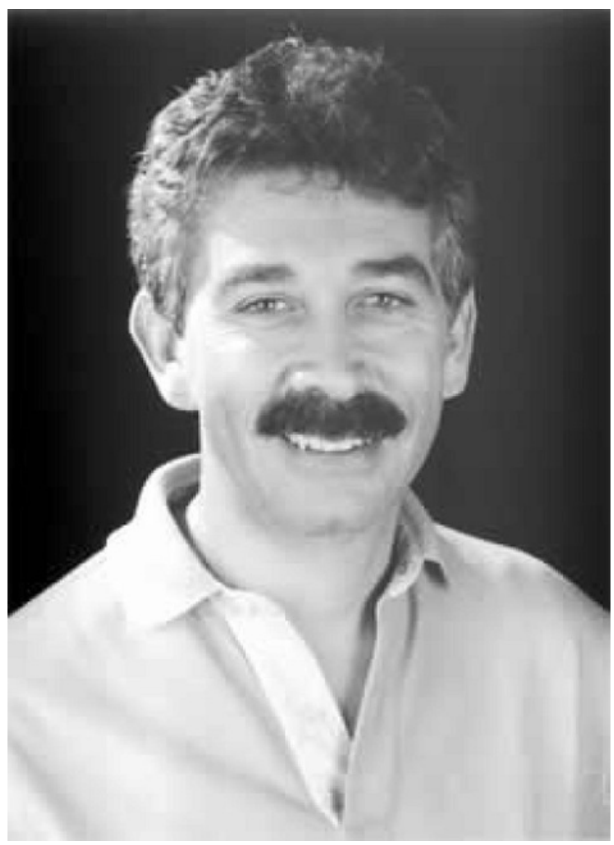

Figure 1 Francisco Arroyo.